# Improved Device Performance of Bulk Heterojunction (BHJ) Hybrid Solar Cells by Optimization CdSe QDs/PCPDTBT ratio

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***Abstract* - In this work, we have successfully demonstrated that device performance of Bulk Heterojunction (BHJ) Hybrid Solar Cells can be greatly enhanced by optimization CdSe Quantum Dots (QDs) loading in photoactive layer. Optimization was reached by various blend concentration, the ratio (w/w) of donor to acceptor was varied between 80% and 90% of CdSe QDs weight content. An optimum QDs loading was found at 86 wt.%, resulting high photo conversion efficiency (PCE) of 3.1 %. The efficiency enhancement is attributed to optimum photon absorption and electron transport leading to an increased short-circuit current density of devices.**

***Keywords: CdSe, quantum dot, bulk hetero junction, solar cell.***

## I. INTRODUCTION

Solution-processed solar cells based on bulk heterojunction (BHJ) organic–inorganic hybrid materials have been developed as an alternative route towards low-cost fabrication, high efficiency, light-weight and flexible large-area devices[1]. Hybrid BHJ solar cells are in principle comparable to that of organic solar cells, the main difference is that inorganic semiconductor quantum dots (QDs) are utilized as electron acceptors instead of fullerene derivatives such as [6,6]-phenyl-C61-butyric acid methyl ester (PCBM)[2]. Various types of QDs such CdS[3], CdSe[4], CdTe[5], ZnO[6,7], $SnO_2$[8,9], $TiO_2$[10], Si[11], PbS[12,13] and PbSe[14,15] have been used so far in BHJ solar cell.

The first polymer:QDs hybrid solar cell was reported in 1996 by Greenham et al., they used CdSe QDs as the acceptor and poly{[2-methoxy-5-(2-ethylhexyloxy)-1,4- phenylene] vinylene} (MEH-PPV) as the donor[4]. However, the power conversion efficiency (PCE) of their device was 0.1 %, which was attributed to ineffective charge transport through CdSe QDs. Nowadays, the polymer poly [2,6-(4,4-bis-(2-ethylhexyl) -4H-cyclopenta [2,1-b;3,4-b′] dithiophene)-alt-4,7-(2,1,3-benzothiadiazole)] (PCPDTBT) is a start-of-the-art electron acceptor for organic solar cells (OSCs) and hybrid solar cells (HSCs) applications [16]. For instance, when blended with ($PC_{71}BM$) in a bulk-heterojunction (BHJ) architecture, power conversion efficiencies (PCEs) above 6% have been achieved with open-circuit voltages ($V_{OC}$) in the range of 0.9 V [17]. Whereas, in HSCs, recently efficiencies of 4% have been reported when combined with CdSe QDs [18]. Although the PCEs of HSCs are lagging behind the fullerene-based cells, they have theoretical the potential to exhibit a better performance because QDs have the features of tunable bandgap, high absorption coefficient, and high intrinsic charge carrier mobility[19].

Many attempts have been dedicated for improving the charge transport, including controlling the nanomorphology [20,21].The nanoscale morphology of the active layer is a crucial parameter for the device performance of HSCs [22–24]. The crucial parameters that dictate device performance of BHJ HSCs are: (i) the composition of the blended photoactive layer, (ii) surface modification of QDs (iii) the drying conditions during the formation of the active layer. There have been many reports on P3HT/CdSe QDs[25,26]. Zhou, have reported the optimum loading ratio CdSe QDs in PCPDTBT was about 87.5 % w/w[27]. However, it still need to be further investigated. Therefore, this work is focused to investigate composition of the blended solution of photoactive layers which play as one of fundamental role in HSCs. We study effect of PCPDTBT:CdSe QDs blend composition on device performance of BHJ solar cells with variation of four CdSe QDs loading ratio (80 % – 90 % w/w).

## II. EXPERIMENT

### *A. CdSe QDs synthesis*

CdSe QDs with an average size of 6.5 nm were synthesized by hot injection method and described elsewhere [28].

### *B. PCPDTBT–CdSe QDs hybrid material blending formation*

First, CdSe QDs products was washed by hexanoic acid washing treatment[29]. Briefly, 1.6 mg CdSe QDs, were dissolved in 4.9 ml hexanoic acid and stirred for 22 min at 110 °C to reduce the amounts of organic ligands [29]. Afterwards, 9.8 ml methanol was injected to the solution and stirred for another 11 min. A second washing step was done by adding chloroform

and methanol with a ratio of 1:3 and stirred for 11 min to precipitate the QDs and remove residual hexanoic acid. Separation CdSe QDs was done by centrifuging the dispersion for 1 min at 14.5 krpm. Final CdSe QDs product were dispersed in chlorobenzene (CB) establishing a concentration of 20 mg/mL. CdSe QDs solution was mixed with 20 mg/mL of PCPDTBT and formed four different loading ratio 80 wt %, 86 wt %, 88 wt % and 90 wt %.

*C. Device fabrication*

The device was fabricated on a structured ≤10 Ωsq ITO substrate. A~70 nm hole transport layer was spin coated of PEDOT:PSS (HC Starck ) at 3000 rpm for 30 s on top. The photoactive layer blend solution spin coated at 1100 rpm for 30 s and followed by a 1 min drying step at 3000 rpm, resulting in a thickness film of about 80 nm. Afterwards, an 80 nm aluminium cathode layer was formed by thermal evaporation. .

## III. RESULT AND DISCUSSION

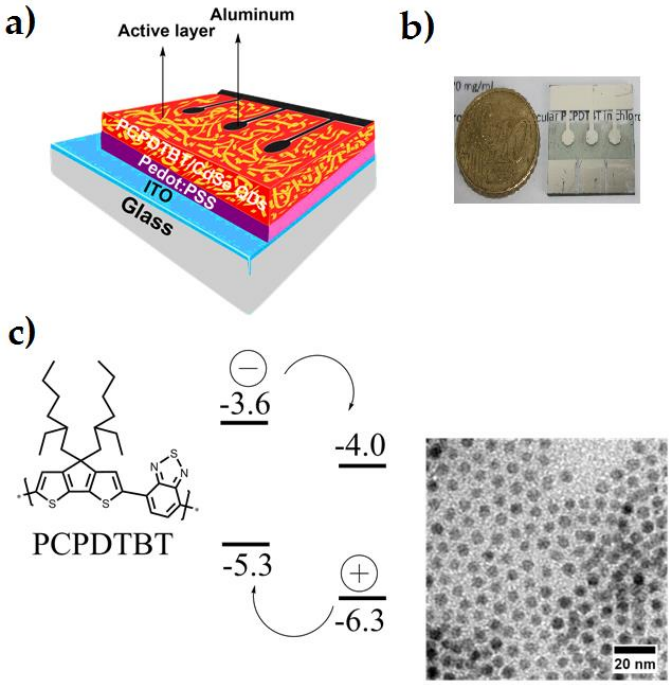


Figure 1. (a) Schematic structure of a typical fabricated solar cell device with an active layer consisting of PCPDTBT and CdSe QDs, (b) photograph of a typical device fabricated in this work (b), and (c) chemical structure (left) and energy level diagram of PCPDTBT in comparison with CdSe QDs (middle), as well as a TEM image of CdSe QDs (right).

Photovoltaic devices were fabricated according to the structure depicted in Figure 1. The highest occupied molecular orbital (HOMO) an lowest unoccupied molecular orbital (LUMO) level of PCPDTBT of -5.3 eV and -3.6 eV respectively were adopted from literature [16]. The valence and conduction band edges of CdSe QDs are expected at about -6.3 eV and -4.0 eV respectively and are referred to data from literature similarly-sized CdSe QDs [30]

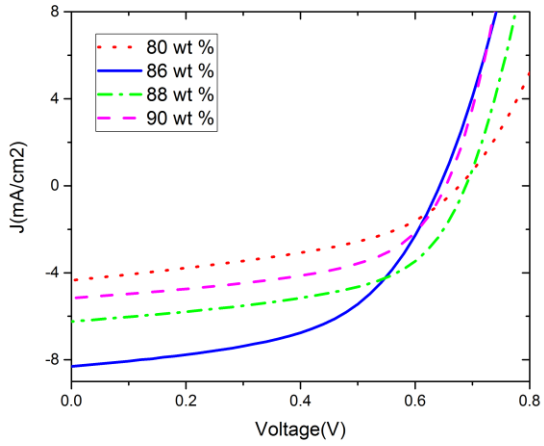


Figure 2. J–V curves of best solar cell devices based on four different loading ratio of CdSe QDs.

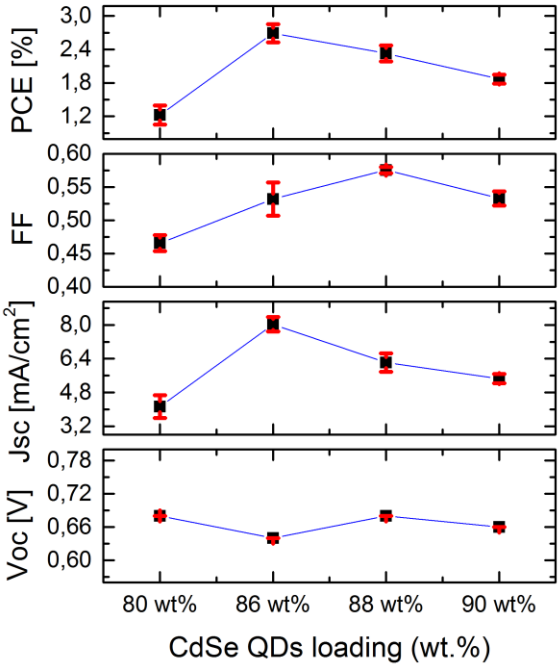


Figure 3 shows the $V_{OC}$, $J_{SC}$, *FF* and PCE values under illumination as function of increasing CdSe QDs wt.% loading in the photoactive layer of hybrid solar cell devices.

All of the cells have been fabricated from the same batch of CdSe QDs. J–V curves of best solar cell devices based on four different loading ratio of CdSe QDs can be seen in Figure 2. In figure 3,it is observed that the PCE of devices varies depending

on the loading concentration of CdSe QDs in the photoactive layer blend. An optimum QDs loading was found at 86 wt.%, which is in agreement with results reported in literature [31,32]. Such high QD loading is preferred because lower loading results in decreased PCE values due to the formation of inefficient QD percolation pathways for electron transport. On the other hand, too high QD loading leads to insufficient photon absorption from the polymer part and lower hole mobility[27]. Table 1 summarizes the devices performance as a function of different CdSe QDs loading. The average values (symbols) and standard deviations are derived from three individual devices located on same substrates.

Table 1 Summarized values of device performances as a function of CdSe QD loading.

| CdSe loading | Voc [v] | Jsc [mA/cm2] | FF | PCE [%] |
|---|---|---|---|---|
| **80 wt.%** | 0.68 | 4.13 ± 0.53 | 0.47 ± 0.01 | 1.22 ± 0.17 |
| **86 wt.%** | 0.64 | 8.03 ± 0.34 | 0.53 ± 0.02 | 2.69 ± 0.16 |
| **88 wt.%** | 0.68 | 6.21 ± 0.44 | 0.58 ± 0.03 | 2.33 ± 0.14 |
| **90 wt.%** | 0.66 | 5.46 ± 0.21 | 0.53 ± 0.01 | 1.87 ± 0.08 |

The results presented in Table 1 show changes in device performance as a function of CdSe QD loading. It can be seen that the performance of the devices tends to rise significantly as the QDs loading is increased from 80 wt. % to 86 wt. %; however, performances started to drop when QDs loading is reaching 88 wt. %. The highest PCE was recorded at 86 wt.%, followed by 88 wt.%, 90 wt.% and 80 wt.% with 2.69 %, 2.33 %, 1.87 % and 1.22 % respectively. Despite all of the devices showed comparable values of VOC, it can be observed that their current density gives significant contribution to the efficiencies. It can be seen that devices based on 86 wt. % CdSe QDs produced a JSC values nearly double as high as for 80 wt. % CdSe QDs-based devices. As a result of this doubling, 86 wt.% CdSe QDs-based exhibited a higher PCE, even more than double compared to that of 80 wt.% based devices.

## IV. CONCLUSION

In summary, an attempt for improving device performances BHJ solar cells using optimization of CdSe QDs loading ratio was demonstrated. Best device performances were obtained by a loading ratio between CdSe QDs and PCPDTBT of 86 wt.% of QDs. An initial PCE up to 2.8 % showed a promising improvement in PCE compared to other ratios. It could be attributed to the improved conductivity of the QDs network due to the suitable amounts of QDs, which provide more direct and continuous pathways for the electron transport. Therefore, it can be concluded that improving the inorganic network is a crucial for the further improvement of hybrid solar cells.

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